

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
2/6/96 - 1/31/97

4. TITLE AND SUBTITLE

User Interfaces for Cooperative Remote Design

5. FUNDING NUMBERS

Grant # N00014-96-1-G004

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES COR:

12a. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Our objective in this research is to allow teams that are physically separated to do detailed design work on large-scale, 3D projects. The specific task is to enable multiple users to stand at each of two (or more) Virtual Workbenches at remote locations and interact effectively for design generation. Specific tasks completed include:

- Organized and segmented the new Navy Arsenal Ship model
- Developed off-axis stereoscopic display and basic tracking mechanisms
- Developed an object data organization
- Generated nearly 1,000 3D objects and classified them using the data organization format.
- Worked on several interaction paradigms, many of which are implemented in the design environment.
- Developed a networking structure
- Put together and are demonstrating a prototype design environment.

In the coming year we will further study issues of collaboration and will also continue our work in enlarging and managing the set of objects in the ship design.

14. SUBJECT TERMS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF
THIS PAGE

19. SECURITY CLASSIFICATION OF
ABSTRACT

20. LIMITATION OF ABSTRACT

User Interfaces for Cooperative Remote Design

Annual Progress Report to

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January 31, 1997

19970317 049

User Interfaces for Cooperative Remote Design Annual Progress Report

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Our objective in this research is to allow teams that are physically separated to do detailed design work on large-scale, 3D projects. We seek to develop new methods to facilitate cooperative remote design utilizing both high- bandwidth networking capability and virtual reality with appropriate graphical interfaces to support the collaborative effort. The specific task is to enable multiple users to stand at each of two (or more) Virtual Workbenches at remote locations and interact effectively for design generation. Although we are just in the first year of this effort, we have made significant progress towards this goal.

To build and test our design environment we needed a large scale and complex design model. We chose the new Navy Arsenal Ship. This is a multiple deck level model and our biggest initial problem was to organize and segment this model so that graphical detail could be handled efficiently and so that individual 3D objects could be moved independently. We separated the model hierarchically along decks and then further along task areas (e.g., galley, mess area, engine room, communications rooms, sleeping quarters, etc.). Initially, we implemented the model using the Simple Virtual Environment (SVE), which provides extensive software support for the creation of virtual applications including handling tracking, interactive tools, virtual menus, and display of 3D objects within the virtual environment. During the Summer of 1996 we switched from SVE to the SGI Performer environment. The main reasons for this is that Performer is highly optimized for running 3D interactive simulations on Reality Engines, Infinite Reality Engines, and other high-end SGI hardware, and it has recently been made more flexible with new capabilities. Its optimizations including advanced handling of graphical details and textures to sustain interactivity and use of parallelism in multiprocessor architectures. New capabilities include the handling of over 30 model formats and integration with Multigen modeling capacities.

After this initial work we have:

- Developed off-axis stereoscopic display and basic tracking mechanisms within the Performer environment.
- Developed an object data organization for the design environment. This involved labeling by base element, function, deck, size, modular grouping, and other attributes. With this structure we can locate and place objects, group them, evaluate their fit and use, and provide input to automatically update CAD databases.
- We have generated nearly 1,000 3D objects and classified them using the data organization format. These are items for the living quarters, galley, and

mess areas, among others. We or others can now generate additional objects in Multigen, 3D studio, Wavefront, or other formats accepted by Performer or Multigen.

- Used the data organization, to develop models for a number of objects in the cargo and engine rooms, living quarters, mess hall, galley, passageways, and other areas on all decks of the ship. These have now been converted into the Multigen format.
- Worked on several interaction paradigms, many of which are implemented in the design environment. These include two-handed manipulation to grab, orient, and stretch or compress objects. Also, we have an interface for pinch gloves, whereby separate gestures involving one finger touching any other can be accurately recognized, and a serial interface for a tool handle that has multiple buttons and can be programmed for different purposes.
- Developed a networking structure that supports the collaborative virtual environment by allowing all objects in the environment to be "shared". By this we mean that each user in the VE will be able to see all objects (models) in the environment and any changes made to those objects. If one user moves a chair, the chair will move for all other users, keeping each user's view of that chair (position, orientation, etc.) consistent with everyone else's. Users will also see graphical representations (avatars) of the other users in the environment. These avatars are themselves "shared" objects.

We have now put together and are demonstrating a prototype design environment. Based on Performer, OpenGL, and Multigen, it is flexible enough for integration with simulations and interfaces supplied by Lockheed-Martin or DARPA. It can work in networked environments involving multiple workbenches, workbenches and displays, HMD systems and workbenches, or HMD systems and displays.

It allows:

- Participants to see representations (avatars) of all users interacting in the environment. The avatars will vary depending on the type of environment. For example, in the networked workbench environment, one might just see representations of collaborators' hands. In an environment involving a workbench and HMD, the person in the HMD would be immersed and might see only her collaborator's hand while the person at the workbench would see an avatar. The avatar would have the position and orientation of the immersed person in the HMD.
- Changes made to the model to be communicated to each participant allowing them to see an up-to-date representation of objects in the environment.

- Participants to communicate with each other through a digital voice channel. While this is not absolutely necessary, we believe that it greatly enhances the collaboration.
- Users to perform simple manipulations (translation, rotation, simple grouped actions) with the individual objects comprising the ship model.

FURTHER WORK

Now that we have our initial system in place, we will coordinate with Lockheed-Martin's simulation-based design efforts. This will include working with Division, which has been chosen to interface its dVISE virtual prototyping software with HLA. We will direct efforts towards integrating dVISE into our collaborative environment.

Georgia Tech has recently won a DURIP grant and will use this funding plus significant matching funds to obtain its own immersive workbench setup. This facility will be compatible with the NRL system. At that time we will begin a joint study involving two workbenches and a long-distance, networked environment. We will further investigate setting up a link between DARPA and NRL for demonstration and further studies of collaboration. This will permit us to study an environment with more than two sites participating and with one or more collaborators at each site.

We will further study issues of collaboration. Working these out will be especially important when we have multiple, networked users. There must, for example, be support for "group memory" since the design projects will be spatially complex with multiple steps and multiple sessions. The collaborators must have support to recall what they did both in individual sessions and across sessions. In addition we must work out protocols for collaboration to reduce latency of interaction and induce efficient sharing of tools. For example, we will institute various roles for collaborators, such as "lecturer and audience", "apprentice and master", and "peers", among others. These roles range from total control of tools and simulation objects on one end to a free-for-all environment (peers) where one collaborator can take over control of a tool without permission. In addition to addressing control and style of work in different ways, these protocols have different impacts on latency since the imposing and removing of locks on tools (and the broadcasting of this information) takes time and can interrupt the flow of interaction.

In line with our study of the multi-user, collaborative environment and issues of data transfer and latency, we will implement a robust networked structure. This will be based on work we are doing now, in conjunction with the Georgia Tech Telecommunications/ Networking Research Group and NRL. (Our present networked interface is based on this work.) The networked structure is based on the concepts of dynamically configurable protocols and adaptable applications. It will dynamically adjust to current network conditions, sacrificing speed for reliability (or vice-versa) based on the type of data. For example, for data from an electromagnetic tracker, it's important to transmit the data as fast

as possible, but it's no big loss if an occasional transmission doesn't make it. Therefore the reliability of the transmission can be sacrificed in order to reduce the latency. However, suppose the actual structure of a model is changed? It's important that all users be notified of this change, making the reliability of the transmission more important than the latency. We will be able to configure the networking in our application to distinguish between these types of transmissions.

We will continue looking at HLA and getting advice on compliance from experts at Georgia Tech, NRL, Lockheed-Martin, and Division. At the moment HLA appears to be just in a prototyping phase; our initial task has been to develop an environment flexible enough to accept HLA when a final form is decided upon. When HLA development moves far enough along, we will implement the appropriate interface for our cooperative remote design environment.

Finally we will continue our work in enlarging and managing the set of objects in the ship design. This will include further methods for grouping, re-grouping (including making new groups), and ungrouping of functional elements in the design space. For the more complicated objects and groups we will introduce multiple levels of detail, which can be handled in the Performer environment. We will also work on integrated detail management strategies involving cost/benefit analyses to maintain interactivity. (These are necessary when handling views containing many groups of objects.) We must also introduce dynamic objects, which allow changes to object structure or function in a simulation-based environment. This will necessitate efficient organization, passing, and incorporation of updates to object attributes (beyond position and orientation) between collaborators.